$|V_{\rm td}/V_{\rm ts}|_{B\to V\gamma}$ an update

TDCP asymmetry $B \to K^*\gamma$ as a (quasi)null-test SM

Roman Zwicky

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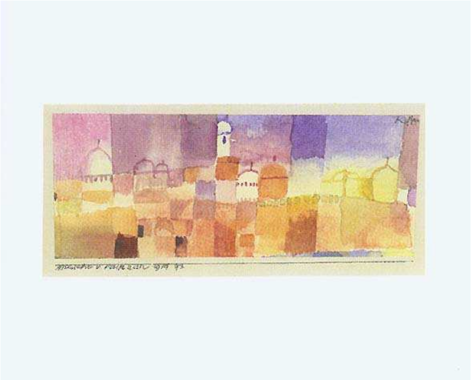

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1. Introduction $B \to (K^*, \rho)\gamma$ ..
   - hard spectator QCD-factorization
   - power correction $1/m_b$: c,u-loops, annihilation

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$$R \equiv \frac{B(B \to (\rho,\omega)\gamma)}{B(B \to K^*\gamma)} \sim \underbrace{\frac{|T_1^{B\to\rho}|^2}{|T_1^{B\to K^*}|^2}}_{(\xi^{SU(3)}_{B\to V\gamma})^{-2}} \frac{|V_{\rm td}|^2}{|V_{\rm ts}|^2}$$

   - $\xi = 1.17 \pm 0.09$ from LCSR [hadronic input: $f_\rho^\perp$, $f_{K^*}^\perp$ & $a_1(K^*)$ (recent progress)]
   - value: $\frac{|V_{\rm td}|^2}{|V_{\rm ts}|^2} = 0.192 \pm 0.016_{\rm exp} \pm 0.014_{\rm th}$
   - comparison 1.UT-fit 2. $f(|V_{\rm ts}|, \gamma)$, 3. B_s-oscillation

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3. TDCP- asymmetry $B \to K^*\gamma$
   - 97’ Attwood, Gronau & Soni $S^{\rm SM}_{K^*\gamma} = O(m_s/m_b)$
   - 04’ Grinstein et al broken soft gluon emission: large grounds dimensional estimate
   - 06’ concrete calculation: small

Operators in $b \to (d,s)\gamma$

$$\mathcal{H}_{\rm eff}^{(d,s)} = \frac{G_F}{\sqrt{2}} \sum_{U=u,c} \underbrace{\lambda_U^{(d,s)}}_{\rm CKM} \left[C_1 Q_1 + C_2 Q_2 + \sum_{i=3,\dots,8} C_i Q_i \right] + {\rm BSM}$$

Effective Hamiltonian (OPE-description), CKM-factors $\lambda_t^s = V_{\rm bt} V_{\rm ts}^*$

$$Q_1{}^U = (\bar{s}U)_{V-A}(\bar{U}b)_{V-A} \qquad Q_2{}^U = (\bar{s}_i U_j)_{V-A}(\bar{U}_j b_i)_{V-A}$$

$$Q_3 = (\bar{s}b)_{V-A}\sum_q (\bar{q}q)_{V-A} \qquad Q_4 = (\bar{s}_i b_j)_{V-A}\sum_q (\bar{q}_j q_i)_{V-A}$$

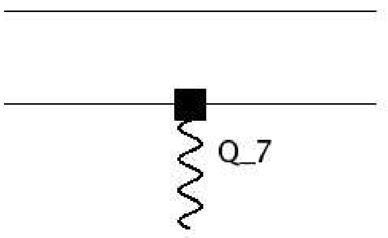
$$Q_5 = (\bar{s}b)_{V-A}\sum_q (\bar{q}q)_{V+A} \qquad Q_6 = (\bar{s}_i b_j)_{V-A}\sum_q (\bar{q}_j q_i)_{V+A}$$

$$Q_7 = \frac{e}{8\pi^2} m_b\, \bar{s}_i \sigma^{\mu\nu}(1+\gamma_5) b_i\, F_{\mu\nu} \qquad Q_8 = \frac{g}{8\pi^2} m_b\, \bar{s}_i \sigma^{\mu\nu}(1+\gamma_5) T^a_{ij} b_j\, G^a_{\mu\nu}$$

- C_i Wilson Coeff. known NLO α_s (NNLO first estimate lately) from “inclusive people”
- C_7 leading $1/m_b$ and α_s $b \to (d,s)\gamma$, add $O(m_s)$-part later
- C_2 $1/m_b$ (power)-correction in $b \to (d,s)\gamma$, but $C_2 \sim C_7$
- $Q_2{}^U$-flavour sensitive, discr. final state

2. $B \to V\gamma$ in pictures and equations

- At $O(\alpha_s^0)$, LO $1/m_b$ only electric penguin



$$\langle V\gamma|Q_7|B\rangle = T_1^V(0)\,(\text{kin})\text{the semileptonic FF}$$

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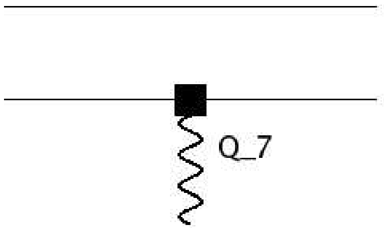
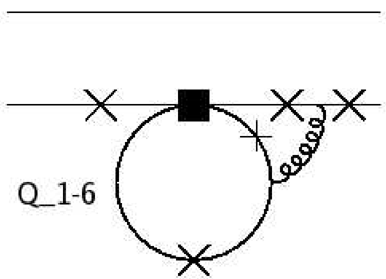
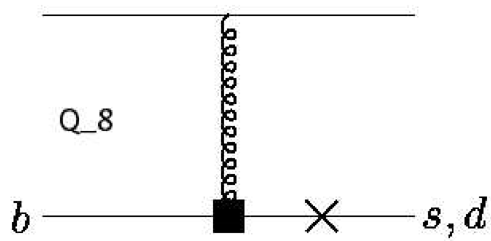


$$\langle V\gamma|Q_7|B\rangle = T_1^V(0)\,(\text{kin})\text{the semileptonic FF}$$

- At $O(\alpha_s)$, LO $1/mb$ **QCD factorization**
  (Bosch et al, Beneke et al, Ali et al 01 ... Becher et al 05 (all order α_s)):

$$\begin{aligned}\langle V\gamma|Q_i|B\rangle &= T_i^I F(B\to V_\perp) + \int_0^1 d\xi du\, \phi_B(\xi)\phi_{V_\perp}(u) T_i^{II}(\xi,u) + O(\Lambda/m_b) \\ &= \#\langle V\gamma|Q_7|B\rangle + O(\Lambda/m_b)\end{aligned}$$

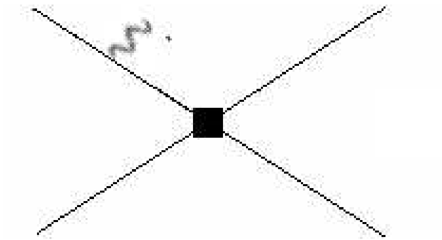


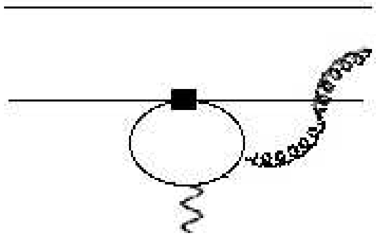


hard-vertex int. T^I hard-spectator int. T^{II}

... $1/m_b$ (power)-corrections

- The operators $Q_2^U = (\bar{D}U)_{V-A}(\bar{U}b)_{V-A}$
  - Annihilation
  - U=(u,c)-loops





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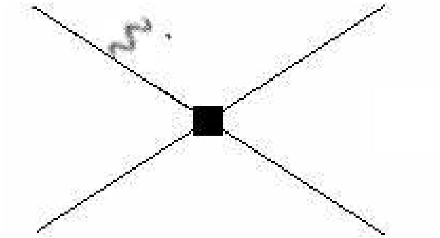

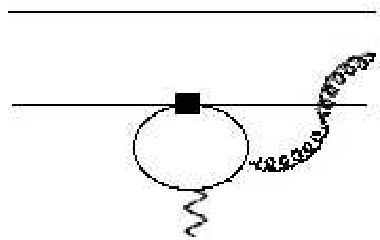

- Parametrization from the literature

$$A(B \to V\gamma) = \langle V\gamma | H_{\rm eff} | B \rangle = \frac{G_F}{\sqrt{2}}(\lambda_u a_7^u + \lambda_c a_7^c) \underbrace{\langle V\gamma | Q_7 | B \rangle}_{\sim T_1(0)}$$

- $$a_7 = \underbrace{C_7}_{\rm incl.case} + \underbrace{\alpha_s(\text{LO} \quad \text{spect.vert.})}_{\rm QCD-fac.} + \underbrace{C_2 \frac{\langle V\gamma | Q_2 | B \rangle}{\langle V\gamma | Q_7 | B \rangle}}_{O(1/m_b)}$$
- spec. V CKM-hierarchy, photon polarization later on

CKM-hierarchy in $B(B \to V\gamma)$

U	u	c
K^*	λ^4	λ^2
ρ	λ^3	λ^3

$\lambda \sim 0.2$

$Q_2^U = (\bar{s}U)_{V-A}(\bar{U}b)_{V-A}$

Need control power corrections!

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A. $B \to K^*\gamma$ only need c-loop (KRSW 97,BZ06) are around 3%

- inclusive case ind. no NP $\Rightarrow T_1^{\text{“exp“}} = 0.28 \pm 0.02$ BB, BFS 04
- $T_1^{\text{LCSR}}(0) = 0.31 \pm 0.04$ BZ 04, hep-ph/0608009 incl SU(3)-progress

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B. Ratio of decay rates

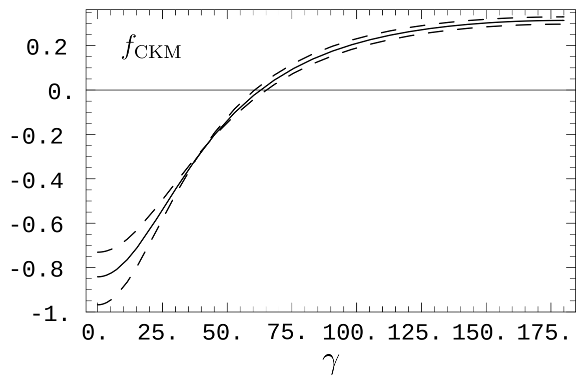
$$R \equiv \frac{B(B \to (\rho,\omega)\gamma)}{B(B \to K^*\gamma)} = \left|\frac{V_{\rm td}}{V_{\rm ts}}\right|^2 \underbrace{\left|\frac{T_1^{B\to\rho}}{T_1^{B\to K^*}}\right|^2}_{(\xi^{SU(3)}_{B\to V\gamma})^{-2}} \left|\frac{a_7^c(\rho)}{a_7^c(K^*)}\right|^2 (1 + \underbrace{\Delta R}_{O(1/m_b)}) \, {\rm Kin}$$

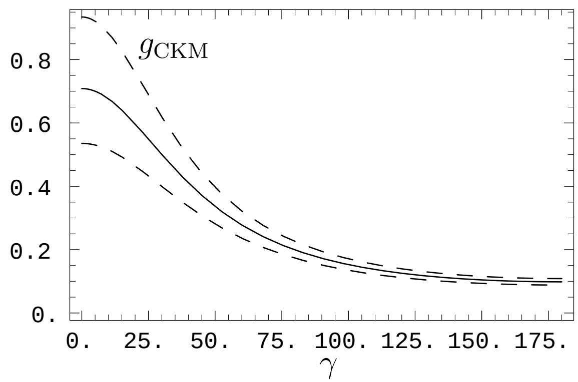
- uncertainty in Wilson-coeff. cancels (maybe also NP !?)
- isospin/CP-average taken to compensate poor statistics
- $R_{\rm exp}$ Belle 05 Babar 06

Need address ΔR

- The generically parametrized $1/m_b$-corr. ($\delta a = (a^u - a^c)/a^c(\rho)$)

$$(1+\Delta R) = |1 + \delta a \frac{V_{\rm ud}V_{\rm ub}^*}{V_{\rm td}V_{\rm tb}^*}|^2 = (1 + f_{\rm CKM}{\rm Re}[\delta a] + g_{\rm CKM}\frac{1}{2}|\delta a|^2)$$





effective suppression

$\gamma_{\rm UT-fit} = 71 \pm 16^\circ$

are accidentally CKM-supressed !! (this is our control here)

and ξ from LCSR

- penguin formfactor

$$\langle V(p)|Q_7|B(p_B)\rangle = \mathrm{kin}\, T_1(0) \quad q = p_B - p \quad q^2 = 0\,\mathrm{photon}$$

  - calculated Light-Cone Sum Rules valid $q^2 < 14\mathrm{GeV}^2$
  - unfort. L-QCD possible $q^2 > 16\mathrm{GeV}^2$ & problem unstable ρ small quark masses

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- hadronic input

$$T_1^V \sim f_V^\perp(1 + c_1 a_1) + \ldots \qquad c_1 \sim O(1)$$

  - $f_V^\perp$ only accessible in theory (contrary $f_V^{||}$)
    taken QCD-sum rules, only exploratory Lattice-QCD calc. of ratios $f_V^\perp/f_V^{||}$
    $\Rightarrow$ efforts desirable
  - first Gegenbauer moment $a_1(K^*)$ recent progress continuous
    - a_1 average momentum of s-quark, const. quark model sugg. $a_1 > 0$
    - (Ball,Boglione 03) $a_1 < 0$!? used unstable non-diagonal sum rules
    - method operator relations (Braun & Lenz 04, Ball & RZ 06) establish $a_1 > 0$
    - stable diagonal sum rules (Khodjamirian et al 04, Ball & RZ 05) $a_1 > 0$
      numerically best

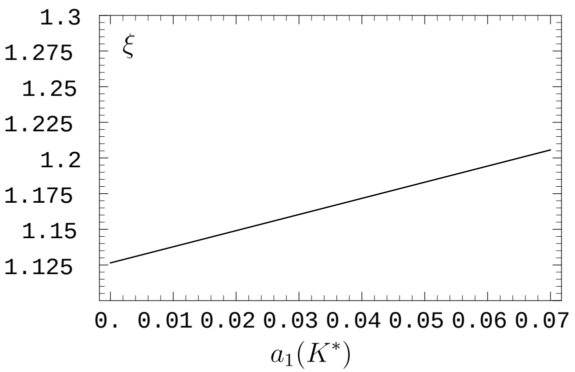
...results from (Ball RZ JHEP 06)

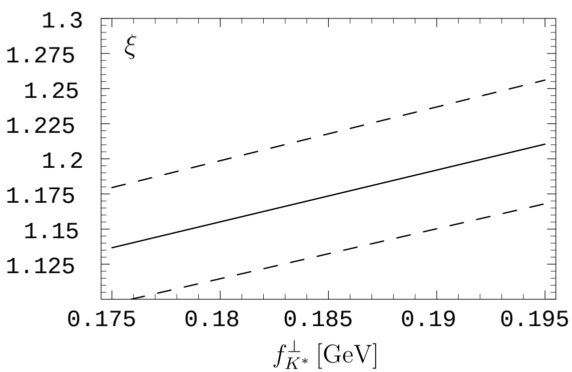
- at $\mu = 1\,\text{GeV}$

$$a_1(K) = 0.06 \pm 0.03 \quad a_1^{\parallel}(K^*) = 0.03 \pm 0.02 \quad a_1^{\perp}(K^*) = 0.04 \pm 0.03$$

- confirmed by Lattice-QCD calculations (low uncertainty) for K
  $a_1(K, 2\text{GeV}) = 0.0453(9)(29)$ QCDSF/UKQCD 06
  $a_1(K, 2\text{GeV}) = 0.055(5)$ QCDSF 06
  scaling $U(2,1) \sim 1.2 \Rightarrow$ central values very close

$$\xi = \frac{T_1^{K^*}(0)}{T_1^{\rho}(0)} = 1.17 \pm 0.09$$





bulk uncert. f_V^T

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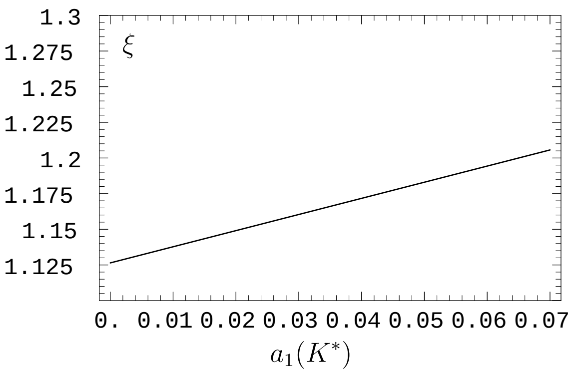

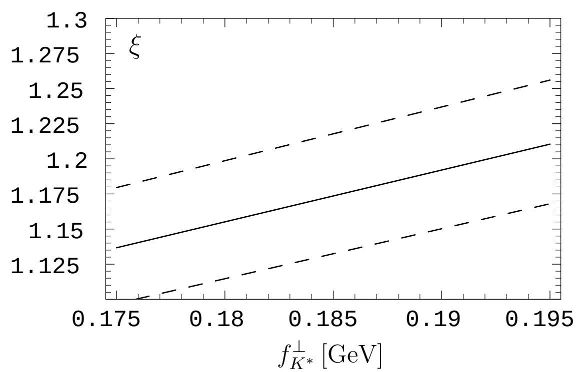

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Comparison & Outlook

$$R_{\rm th} = \left|\frac{V_{\rm td}}{V_{\rm ts}}\right|^2 (0.75 \pm 0.11_{(\xi)} \pm 0.03_{(a_7,\gamma,|V_{\rm ub}/V_{\rm cb}|}) $$

$$R^{\rm Belle}_{\rm exp} = 0.032 \pm 0.009 \quad |V_{\rm td}/V_{\rm ts}| = 0.207 \pm 0.027_{\rm ex} \pm 0.016_{\rm th} \quad \text{v1 only Belle}$$
$$R^{\rm HFAG}_{\rm exp} = 0.024 \pm 0.006 \quad |V_{\rm td}/V_{\rm ts}| = 0.179 \pm 0.022_{\rm ex} \pm 0.014_{\rm th} \quad \text{v2 incl.Babar} - \text{bound}$$
$$R^{\rm HFAG}_{\rm exp} = 0.028 \pm 0.005 \quad |V_{\rm td}/V_{\rm ts}| = 0.192 \pm 0.014_{\rm ex} \pm 0.016_{\rm th} \quad \text{v3 incl.Babar} - \text{meas.}$$

	$R^{\rm HFAG}$	UT-Fit	$f(\gamma, \|V_{\rm ub}/V_{\rm cb}\|)$	$\Delta m_s^{\rm CDF}$
$\|V_{\rm td}/V_{\rm ts}\|$	0.192	0.198	0.216	0.206
$\Delta_{\rm th}$	0.016	0.010	0.029	0.008
$\Delta_{\rm ex}$	0.014		$0.007\,(\Delta\gamma \sim 4^\circ)$	

- no indic. of NP, nevertheless NP could cancel in ratio
- Potential $R^{\rm th}_{B\to V\gamma}$:
  - theory: $\sim 0.010\,(6\%)$ with better $f_V^\perp$
  - experiment: $5\%_{K^*} \leq (5+..)\%_\rho$

3. or C. Time dependent CP-asymmetry $B \to K^*\gamma$

- Key idea $\bar{B}^0$ decay $(V-A)$-interaction produce predominantly left handed photons
  Beyond SM anything possible .. enhanced $m_{\rm NP}/m_b$

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$$A_{CP} = \frac{\Gamma(\bar{B}^0(t) \to \bar{K}^{*0}\gamma) - \Gamma(B^0(t) \to K^{*0}\gamma)}{\Gamma(\bar{B}^0(t) \to \bar{K}^{*0}\gamma) + \Gamma(B^0(t) \to K^{*0}\gamma)} = S \sin(\Delta m_B t) - C \cos(\Delta m_B t)\,,$$

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- Gronau,Attwood & Soni 97 since LO operator

$$Q_7 = \frac{e}{8\pi^2}\left[m_b \bar{s}\sigma_{\mu\nu}(1+\gamma_5)b + m_s \bar{s}\sigma_{\mu\nu}(1-\gamma_5)b\right] F^{\mu\nu} \equiv Q_7^L + \frac{m_s}{m_b} Q_7^R$$

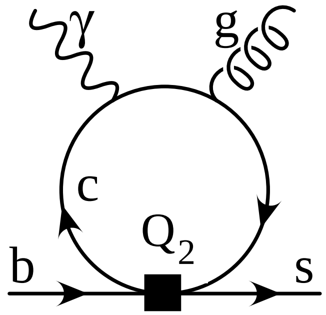
Time dependent CP asymmetry

$$S^{{\rm SM},s_R} = -\sin(2\beta)\,\frac{m_s}{m_b}\,(2 + O(\alpha_s)) \sim (2-3)\%$$

N.B. $O(\alpha_s)$-correction calculable QCD-F.

what about NLO operators

- Grinstein et al 04 futher contribution from soft gluon emission, c-loop from Q_2^c



$$\mathrm{non-factorizable}$$

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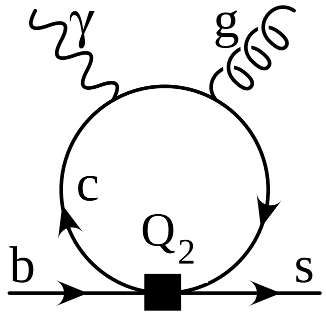

$\mathrm{non-factorizable}$

- SCET based analysis resort dimensional estimate of matrix element and obtain

$$|S^{\mathrm{SM,soft\ gluons}}| = 2\sin(2\beta)\left|\frac{C_2}{3C_7}\right|\frac{\Lambda_{\mathrm{QCD}}}{m_b} \approx 0.06\,.$$

reach conclusion: $S^{\mathrm{SM}}_{K^*\gamma} \sim 0.1$ with large uncertainties

Quantitative analysis

- idea: on-shell photon, c-quark heavy perform a local OPE KRWS 97 ...checked

$$
\begin{aligned}
Q_F &= ie^{*\mu} \int d^4x e^{iqx}\, \mathrm{T}\{[\bar{c}(x)\gamma_\mu c(x)]\, Q_2^c(0)\} \\
&= -\frac{1}{48\pi^2 m_c^2}(D^\rho F^{\alpha\beta})[\bar{s}\gamma_\rho(1-\gamma_5) g \widetilde{G}^a_{\alpha\beta}\frac{\lambda^a}{2}\, b] + \ldots
\end{aligned}
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- Remains calculate matrix element

$$\langle K^*(p,\eta)\gamma(q,e)|Q_F|B\rangle = \left\{ L\epsilon_{\mu\nu\rho\sigma} e^{*\mu}\eta^{*\nu}p^\rho q^\sigma + i\widetilde{L}[(e^*\eta^*)(pq) - (e^*p)(\eta^* q)]\right\}$$

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$$

- The foll. comb. contributes R-handed photons Ball RZ 06

$$
a^c_{7R} = C_7\,\frac{m_s}{m_b} - C_2\,\frac{L - \widetilde{L}}{36 m_c^2 m_b T_1^{B\to K^*}(0)}\,.
$$

Remains to estimate $L - \tilde{L}$

- already KRWS 97 used 3-pt sum rules
  in context of LD contribution to $Br[B \to K^* \gamma]$

$$L = (0.55 \pm 0.1)\,\mathrm{GeV}^3, \qquad \widetilde{L} = (0.70 \pm 0.1)\,\mathrm{GeV}^3\,.$$

  uncertainty only variation Borel-parameter (crude)
  known not to be reliable for $B \to \mathrm{light}$, higher order op. grow powers of m_b

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- From LCSR Ball RZ 06

$$L = (0.2 \pm 0.1)\,\mathrm{GeV}^3\,, \quad \widetilde{L} = (0.3 \pm 0.2)\,\mathrm{GeV}^3\,, \quad L - \widetilde{L} = -(0.1 \pm 0.1)\,\mathrm{GeV}^3\,.$$

  “ironically“ the difference is nearly the same !

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- already KRWS 97 used 3-pt sum rules
  in context of LD contribution to $Br[B \to K^*\gamma]$

$$L = (0.55 \pm 0.1)\,\mathrm{GeV}^3, \qquad \widetilde{L} = (0.70 \pm 0.1)\,\mathrm{GeV}^3\,.$$

  uncertainty only variation Borel-parameter (crude)
  known not to be reliable for $B \to \mathrm{light}$, higher order op. grow powers of m_b

- From LCSR Ball RZ 06

$$L = (0.2 \pm 0.1)\,\mathrm{GeV}^3\,, \quad \widetilde{L} = (0.3 \pm 0.2)\,\mathrm{GeV}^3\,, \quad L - \widetilde{L} = -(0.1 \pm 0.1)\,\mathrm{GeV}^3\,.$$

  “ironically“ the difference is nearly the same !

- L and $\widetilde{L}$ are $\sim \zeta_3^{\|}$ normalization twist-3 .. analogue of f_K

$$\langle 0|\bar{q}Gs|K^*\rangle = \zeta_3^{\|}(\ldots)$$

  determined from QCD sum rules (diffcult) other methods ? lattice ?
  no-reasonable constraints from experiment

Final result & comparison with experiment

$$S^{\mathrm{SM},s_R} = -\,2\sin(2\beta)\,\frac{m_s}{m_b} - 0.027 \pm 0.006(m_{s,b}) \pm 0.001(\sin(2\beta))$$

$$S^{\mathrm{SM,soft\ gluons}} = -\,2\sin(2\beta)\left(-\frac{C_2}{C_7}\,\frac{L-\tilde{L}}{36 m_b m_c^2 T_1^{B\to K^*}(0)}\right) = 0.005 \pm 0.01$$

as comp $|S^{\mathrm{SM,soft\ gluons}}| \sim_{\mathrm{dim.est.}} 0.06$ Grinstein et al

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$$S^{\mathrm{SM}} = -0.022 \pm 0.012^{+0}_{-0.01}{}_{\alpha_s}$$

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- which has to be compared to

$$S_{\mathrm{BaBar}} = -0.21 \pm 0.40\,(\mathrm{stat}) \pm 0.05\,(\mathrm{syst}) \quad \text{BaBar} \quad (232 \cdot 10^6\ B\bar{B}\ \text{pairs}),$$
$$S_{\mathrm{Belle}} = -0.32^{+0.36}_{-0.33}\,(\mathrm{stat}) \pm 0.05\,(\mathrm{syst}) \quad \text{Belle} \quad (535 \cdot 10^6\ B\bar{B}\ \text{pairs}),$$

  and $S_{\mathrm{HFAG}} = -0.28 \pm 0.26$ waiting for BaBar update !

Conclusions & Outlook

- $B \to V\gamma$ control power corrections

A. rate $B \to K^*\gamma$

- recent progress on $a_1(K^*)$ QCD-F & LCSR consistent with rate

B. $B \to K^*\gamma$ vs $B \to \rho\gamma$ constraint on $|V_{\rm td}/V_{\rm ts}|$

- power corrections accidentaly CKM supressed
- no signals NP .. compataible number 1.B_s-osc 2.UT-fit aram.
- yet progress $f^{\perp}_{K^*,\rho}$ desirable for improvement.. lattice-QCD ?

C. TDCP-asymmetry $B \to K^*\gamma$

- leading $C_7\ m_s/m_b$ suppressed spin-flip $\sim 2 - 3\%$
- soft gluon emission ... not too large $\sim 0.5\%$
- remains (quasi)-null test for SM

- u-quark loop & annihilation remain homework ... allow attack further observables $S_{\rho\gamma}$
- not covered: CP-asymmetry extended $B \to (K_s\pi)\gamma$ Dalitz-Plot analyis can dist. Q_7 from Q_2 eliminate soft-gluons high statistic Gershon et al 04

Merci pour votre attention !